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A FUNDAMENTAL STUDY OF ROLLING CONTACT FATIGUE

Quarterly Progress Report No. 7
November 1, 1962 to February 1, 1963

Submitted by:

M.J. Hordon
P.F. Weihrauch

Alloyd Electronics Corporation
35 Cambridge Parkway
Cambridge 42, Massachusetts

Prepared under:

Contract No. W61-0656-c
Department of the Navy
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Attention: RAPP-4

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I. INTRODUCTION

This report presents design data and experimental results on the basis of which an experimental approach was evolved for the investigation of torsional fatigue in fluid environments under Phase II of Alloyd Electronics Corporation program 63-GRX-1 during the period November 1, 1962 to February 1, 1963. In addition, preliminary results of fatigue life of AISI E52100 steel in different fluid environments is presented.

The object of this investigation is two-fold; to provide torsional fatigue data on tool steels in lubricating environments and to generate basic knowledge of the effect of fluid environment on the deformation mechanisms which result in fatigue failure. Although the varied effects of fluid environment on fatigue life have been well documented in the literature, little basic information on the material-fluid interaction and its effect on the deformation mechanisms has resulted.

II. TORSIONAL FATIGUE STUDIES

A. Design of Apparatus

The design of the torsional fatigue machine and torsion specimen was presented in Progress Report No. 6.

This machine consisted of a large mild steel block into which one end of the specimen was rigidly mounted. A lever arm was attached to the free end of the specimen.

This lever arm was to be driven at one end by an alternating current electromagnet. The resultant periodic motion of the lever arm in turn would place the specimen in torsion with the same period of oscillation as the lever arm.

During this reporting period the torsion fatigue machine was built. Three alternating current electromagnets were purchased from Engineering Specialties Company. The magnets are capable of producing fields of five, ten and twenty pounds of force, respectively, over a wide range of frequencies.

The electronics to power the magnets were also purchased and constructed. The power circuit consists of an Altec 260 Ampere Amplifier and a Hewlett-Packard Model 202C Low Frequency Oscillator to adjust the frequency of the magnet to the natural frequency of the lever arm-torsion specimen combination. The electronics include variable capacitance which can be added to the power circuit either in parallel or in series with the magnet in order to adjust the impedance of the circuit.

The magnets also have a resonance peak at which the magnetic flux is maximum. This resonance peak can be altered by changing the total impedance of the magnet circuit. As a result the magnetic resonance can be tuned to correspond to the natural frequency of the lever arm-specimen combination giving the maximum torsional stress and strain.

B. Lever Arm Specimen Modifications

Initially, mild steel specimens were fabricated in order to find a design that would give the stress levels necessary for achieving torsional fatigue in short time tests. These practice specimens were made with a 2 inch gauge length and diameters of 1/8 inch, 1/4 inch and 3/8 inch. These specimens were tested in air.

It was found that both the 1/4 inch and 3/8 inch diameter specimens had natural frequencies to which the magnetic resonance could be easily tuned. However, the force supplied by the magnet was not sufficient to drive the specimens at stress levels above 20,000 psi.

Using the thinner specimen, the natural frequency was greatly reduced and the magnet could not be tuned to give sufficient force at this frequencies to drive the specimen at 30,000 psi.

In order to overcome these difficulties, the torsion specimen-lever arm combination was redesigned to the dimensions of Figures 1 and 2, respectively.

The reduced gauge length of this specimen and the tapered lever arm result in a higher natural frequency; i.e. one which more closely corresponds to the resonance peak of the electromagnet. Furthermore, the longer lever arm and shorter gauge length result in a sufficiently high magnetic force to twist the specimen at the stress levels necessary for short time fatigue failure to take place. With this combination the natural frequency is 96 cycles per second and in 1 hour the specimen is given 345,600 complete stress cycles.

C. Materials

Rod stock of both vacuum melted and air melted 52100 steel was obtained from the Crucible Steel Co. The compositions of these steels are shown in Table I.

TABLE I

Composition of Torsional Fatigue Specimens

	Composition, %								
Material	C	Mn	P	S	Si	Ni	Cr	Mo	Cu
Air Melted 52100 Steel	1.05	0.35	0.009	0.010	0.32	0.20	1.38	0.07	0.13
Vacuum Melted 52100 Steel	1.03	0.35	0.007	0.007	0.25	0.08	1.44	0.03	0.09

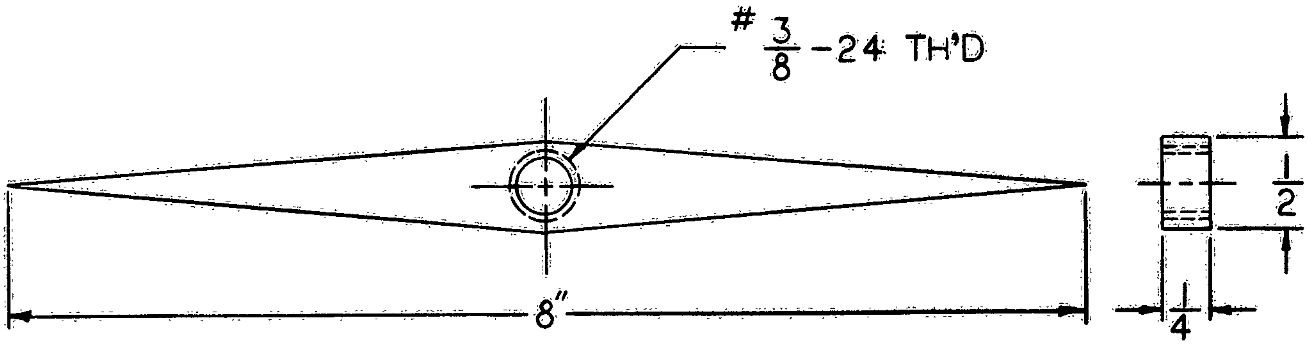

Figure 1 - Modified Design of Torsional Fatigue Lever Arm.

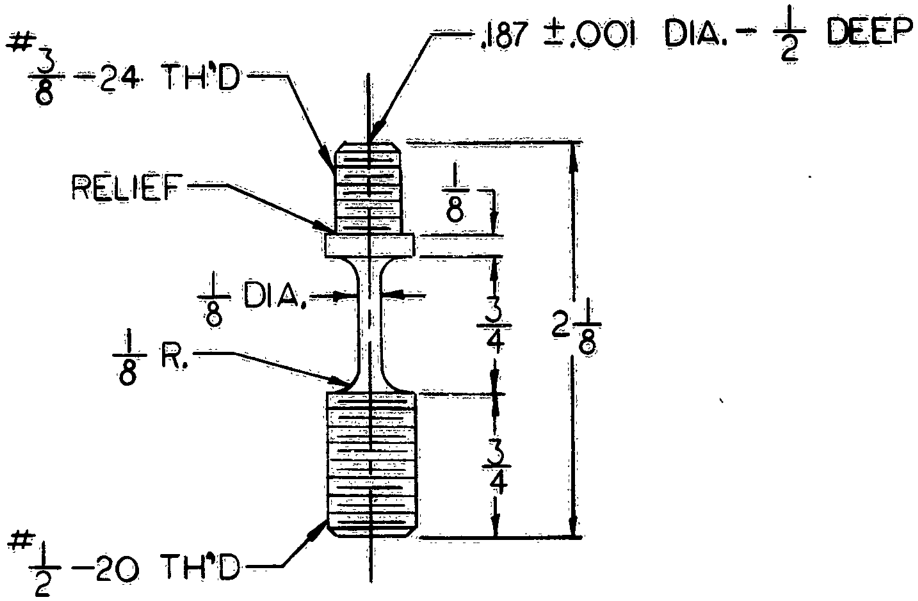

Figure 2 - Modified Design of Torsional Fatigue Specimen.

Initially, the program will be concerned with air melted 52100 steel. The as-received stock was annealed at 1550°F for 15 minutes and furnace cooled in order to facilitate machining. The stock was then machined to the dimensions of Figure 2.

D. Testing Environments

Two types of oils were chosen as testing environments for 52100 steel, turbine oils and paraffin base mineral oils. A group of turbine oils answering the specification MIL-L-2190T and having viscosities from 150 to 190 centistokes at 100°F, and a group of parrafin base mineral oils of viscosities from 5 to 10 centistokes at 100°F were obtained from the Mobil Oil Company.

III. MATERIAL PREPARATION AND TESTING

A. Preparation of 52100 Steel

It was decided to use 52100 steel in three conditions; (1) annealed at 1550°F and furnace cooled giving a Rockwell C hardness of 17, (2) annealed at 1550°F and oil quenched followed by a 2 hr. temper at 275°F giving a Rockwell C hardness of 65, (3) annealed at 1550°F and oil quenched followed by a 3 hr. temper at 375°F giving a Rockwell C hardness of 55.

After machining the stock to the dimensions of Figure 2, the specimens are given the above heat treatments in a hydrogen atmosphere in order to eliminate any scaling.

The specimens are then placed on a lathe and lapped with a very fine paper to remove surface irregulaties and points of stress concentration.

B. Measurement of Stress Level

The elastic fiber stress in the specimen is given by equation (1):

$$\tau = \frac{T \times d}{2J_C} \qquad (1)$$

$$J_C = \pi d^4/32 \qquad (2)$$

where J_C is the polar moment of inertia, T is the torque acting on the specimen and d is the specimen diameter. The torque T is given by:

$$T = P \times r \qquad (3)$$

where r is half the length of the lever arm and P is the force acting normal to the end of the lever arm. The torsional stress can then be expressed as:

$$\tau = \frac{16\ r\ P}{\pi d^3} \qquad (4)$$

The stress can be calculated from Equation (1) by finding the force on the lever arm. The problem can be further reduced to measuring the deflection of the lever arm by making a static load vs. deflection curve. Thus by measuring the deflection of the lever arm and finding the force necessary for this deflection, the fiber stress can be calculated.

Several techniques for measuring the deflection of the lever arm were tried. These included: (1) direct viewing of the end of the lever arm through a telescope, (2) electrically reading a signal resulting from the change of capacity of two parallel plates one of which was stationary and the other attached to the oscillating lever arm and (3) placing the point of the lever arm at a high voltage and tracing the motion of the point by the electrical discharges through a sensitized paper.

The latter technique was found to be the most accurate and reliable method. With this technique deflection can be read with an accuracy of $\pm$ 0.005 inches or to $\pm$ 1,500 psi.

IV. PRELIMINARY EXPERIMENTAL RESULTS

With the specimen dimensions finalized to a 1/2 inch gauge length and 1/8 inch diameter, fabrication of specimens of 52100 air melted steel was begun.

A static loading curve was made by loading the lever arm in increments of 100 grams or 2310 psi and measuring the deflection of the lever arm. The curve is shown in Figure 3.

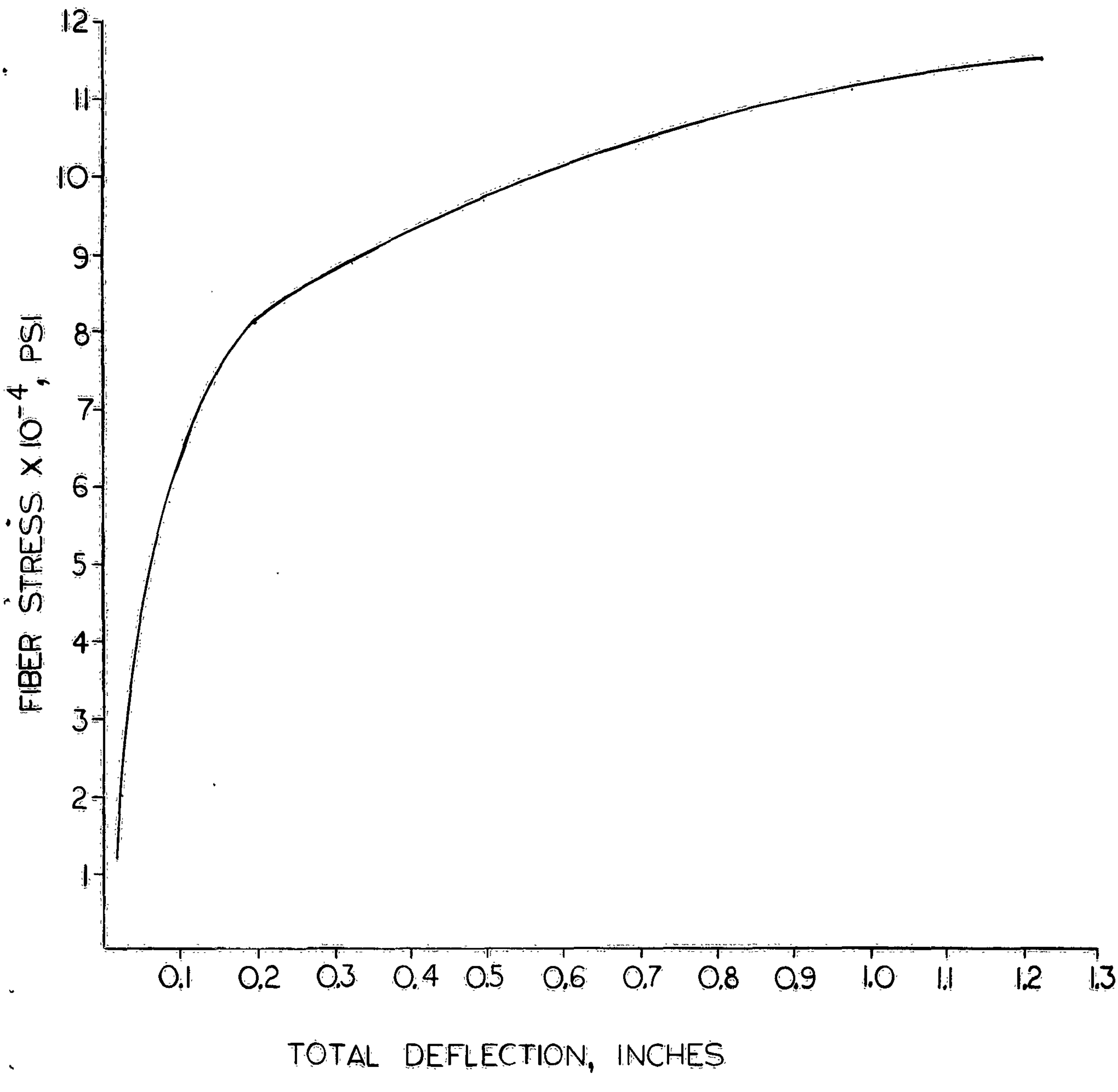

Figure 3 - Static Deflection Curve for fully Annealed 52100 Steel with 1/8 inch diameter and 1/2 inch gauge length.

Testing of the 52100 specimens was begun and it was found that at a maximum fiber stress of 70,000 psi failure took place in 1,244,000 cycles. Testing in the low viscosity turbine oil at the same stress level produced fatigue failures in 652,400 cycles while in the high viscosity turbine oil the number of cycles to failure increased to 744,000 cycles.

The initial test specimens did not break on the theoretical plane 45° to the specimen axis. This provided evidence that the loading was not pure torsion but that some reversed bending was present in the specimen. The addition of a support to the torsion machine to eliminate the bending stresses has resulted in failures on the theoretical 45° plane for pure torsion.

FUTURE WORK

During the next reporting period work will continue to evaluate the fatigue life of 52100 steel as a function of applied stress, prior heat treatment, lubricant base stock and lubricant viscosity. Metallographic examination of 52100 steel fatigued under the various conditions will be initiated in order to determine the metallographic changes that accompany fatigue failure.